G.S.Maxwell

MANUAL OF INSTRUCTION

IN

FORGE AND MACHINE WORK,

With Figured Drawings of Methods and Exercises
Used in the Fowler Shops of
Kansas University.

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By FRANK E. WARD,
Superintendent of Fowler Shops and Shop Instruction, Instructor in Machine Work and
Mechanical Methods and Practice.

INTRODUCTION.

This little book outlines the student's actual work in the Fowler Shops of the University of Kansas. It is written by a practical mechanic, trained in the rolling-mills and machine shops of Joliet, and formerly Superintendent of the Bates Machine Company; it is written in the spirit and language of the machine shop; it is written after a twelve-years experience with young men in this University.

The Fowler Shops were founded for two purposes. First: To train young engineers in *correct methods* of machine practice. Second: To develop the individual manual skill necessary for the modern engineer. It is the purport of this book to outline a method to accomplish both.

It is not the *only* method, and perhaps not the *best*, but it has proven a successful method.

With this brief introduction, I desire to express my appreciation of Mr. Ward's ability and his conscientious instructorship of young men.

LUCIEN I. BLAKE,
Director Fowler Shops.

PREFACE.

After twelve years' experience as instructor in forge and machine work, and with previous training in practical work as machinist and foreman of machinists, the writer is prompted to put this book in print for four reasons :

I. To place in book form the various blue-prints and sketches which have been used and approved as the most desirable course to give on the subjects named, and these arranged to conform with the limited time which the student has for work.

II. To give in written form much general instruction which otherwise must be verbal.

III. To show the application of each step in the work, and to give other similar methods that could be used under varied conditions.

IV. To produce a well-bound pocket-book, to be carried by the student to the shop or room for reference, so that all may be well prepared to work.

Shop Ethics.

The first and most important lesson for the beginner is to learn to work harmoniously with others, who have equal rights and privileges. And the following suggestions will help those who try to do right.

I. Talk but little, and only about your own work. Pass no remarks about others' troubles and take no special notice of them, unless requested.

II. Borrow no private tools and be neat and considerate with the tools for general use. Check out special tools from the tool-room, and return them as soon as you can conveniently. Lock up your private tools only.

III. Be prompt to begin work and work faithfully until quitting time.

IV. Keep your tools picked up and everything clean and in good order, so that when you leave you will not be called back.

V. Be deliberate and thoughtful. Much work is spoiled by hasty workmen. Your instructor can help a thoughtful student.

VI. Do not tire your eyes by close watching of the fire or of moving parts of machinery. Use calipers for close measurements, thus measuring by touch instead of sight. The most skillful workmen measure to within one-thousandth of an inch by touch with their calipers.

VII. Prepare to get dirty and learn to use hot water and soap on your face and hands. Take off your good clothes and put on overalls. Relish and make a business of your work.

VIII. Owing to the demand for the use of machine tools and forges, the instructor will not hold them for regular men beyond a reasonable time, say fifteen minutes, and will then turn them over to students doing extra work, on application.

Student's Equipment of Private Tools.

Each student makes a deposit of three dollars with the Treasurer of the University for the above equipment, which is valued as follows:

Key for clothes locker	$0.25
Key for tool drawer	.25
Five tool-room checks	.25

Freshman Tools.

1—9″ scale	.35
1—4″ Starrett's hair-spring calipers	.65
1—4″ Starrett's double-blade square	1.25

Sophomore and Junior Tools.

1—6″ spring-tempered scale	.85
1—6″ Starrett's hair-spring calipers	1.00
1 graduated center gauge	.40

Files are provided when needed. Steel to make lathe tools is given to Freshmen. These tools are numbered and are used all through the course in

machine work, but are retained with all private tools at the end of each year.

The tool-room checks are given in exchange for tools of special use, such as drills, reamers, and taps. The check is forfeited when the tool is not returned on time or at night, and when tools are lost or broken carelessly the amount is taken from the deposit. However, with very few exceptions, the deposit has been all refunded.

The keys should be placed on a ring with a brass tag bearing the owner's name.

Apply at the office for lost articles.

CHAPTER I.

Forging and Tempering.

When the stndent enters upon this work, it is assumed that he has no knowledge of the subject at all. Sometimes those who have previously worked at forging find it difficult to put aside their first impressions and to take up better methods.

There are several ways to do every piece of work, but there is always the best way. A student who is deficient in mechanical ability can rarely discern the best; one way appears to him about as good as another; he adopts a certain order because he is told to do so; when his work is compared with good work, he sees no great difference; he does not see that an eighth of an inch more or less does any harm, or that 80 degrees or 100 degrees is not as good as 90 degrees. One side of the anvil is the same as the other, and he has but little command of motion.

When work is started right, every serious, well-balanced student does passably well in it. It is a mistake to insist upon excellence in everything; a partial failure in a single direction should not prevent his going on in the course. Instead of trying to force

all into the same mold, it is our duty to give each full liberty of growth, and yet keep to our standard of requirements.

All who attempt to make forgings should remember that the art of forging has been recognized through all ages as a trade worthy of the life-work of many of the world's best men. And what we do with iron by heat and hammer will be good or bad, according to our skill and patience. All that is done must be with eyes, hands, and judgment.

The operations of a forge shop involve a personal knowledge of four things:

1. How to heat the piece to be operated upon.
2. How to hold it.
3. How to strike it.
4. The kind of metal and the effect of the work and heat upon the metal.

I. How to Heat.

The fire on a forge should receive constant attention, but this does not mean constant poking or watering; but rather to the contrary.

The coal used in these shops is the best to be had for the purpose, and will do effective work. It is not entirely consumed until it becomes a white ash or clinker. The first thing to do is to separate the partly burned coal or coke from the ash; this is easy

when the coke has not been poked and broken up into small pieces.

Start a fire with wood shavings and put some of the coke upon the fire, making a small heap in the center. Then pack damp coal around to keep in the blast, and use the remainder of the coke to feed the fire, for it is comparatively free from gas. When more coke is needed, the banks on the side can be used if coked, and new banks made, or fresh coal can be put close to the fire and allowed to blaze for a while until it is partly coked. The whole secret of a clean fire lies in coking the fine coal into lumps the size of a walnut, and allowing them to so remain until used up. To do this, great care must be exercised in the use of the blast; shut it off to save a good fire and be careful not to use so much blast as to blow large, lumpy, sparks out which mix with the coal on top of the forge, which keep it from coking, and give the coal a lifeless appearance. The forges are provided with shakers to shake out the fine ashes without disturbing the banks of coal. Learn to be economical with coal for your own good. A fire well banked should last five hours on light work.

In regulating the fire it should not be much hotter than the desired temperature (heat); excessive heat will overheat exposed small points.

If the fire is properly kept, a very small amount of blast will do the work except in large welding; too much air cools the metal.

The fire should be so arranged that the metal can be placed horizontal and covered and yet be easily seen, if the coke is large. See that there is plenty of coke under the metal. If the blast does not come through, take a small rod and stick it straight down to the tuyere and close to the metal; this hole will be all that is needed: never should the fire be poked over. Turn the work over without removing it. Give the fire time to do the heating; keeping your mind on the next operation, so no time is lost while the metal is hot.

There are three periods of degrees of heat which the writer wishes to make use of to illustrate the proper heat for metal. The first is called a *low heat*, which is before the metal begins to scale. The second, or *high heat*, extends to the point where the scale melts and begins to drop into the fire, if not turned, and to fly out into sparks. The third heat is a *welding heat*.

Each one of these heats is variable within the limits mentioned; but the student must soon learn to use the heat desired within these limits. Too often finished work is heated to a high heat—thus causing a scale to be removed and leaving it rough and (so called) burnt. So the low heat is used on metal that is finished and that should not be scaled. Metal is bent, shaped, and steel is hardened at this heat.

The high heat is used where metal is to be forged

and can afterwards be finished by the hammer when it cools to a low heat.

The welding heat is used to weld all metals, refine iron, for upsetting, or when a great amount of forging is to be done on iron or soft steel.

II. How to Hold.

The hand holding the tongs or rod must be intimately related with the hammer and anvil. The height will tend to keep the work straight if it is kept turning; or if it be held too high or too low, it will crook the work so it cannot be turned. In some cases it should be turned after each hammer blow; this is done partly by the wrist and partly by rolling in the hand.

III. How to Strike.

A 2-pound hammer is mostly used for this work with a 125-pound anvil; the face of both are slightly rounded. Hold the hammer firmly while directing blow, but the muscles of the arm should be relaxed to allow the hammer to rebound. Avoid a pushing movement and hunching the shoulders. Keep nearly erect, moving the back and shoulders but little; stand within easy reach of the anvil.

The end of the hammer that has a straight or cross pein is used to spread metal—a sphere can

be made into a flat ellipse or oval by scoring it with this cross-pein to spread it one way more than the other, while the smooth face would tend to make the outline circular. The round edge of the anvil is for the same purpose. Forgings should be hammered hard enough to cause the ends and sides to bulge out. If the hammering is too light, the outside only will be stretched and internal cracks started, which will develop in bending or hardening. To accomplish this it is best to keep a forging square when possible and change it to a round or flat when nearly to the size.

IV. The Kind of Metal,

and the effect on it should be the constant study.

Iron during making is melted in a puddle and taken out in layers, and its fiber is lengthwise like that of wood. By hammering it cold, until it cracks, the grain will show to be like wood. When a good piece of iron is broken, it will show a grain like broken wood. So we can not hammer iron much at a "low heat" until it is refined by welding the grain close together. This is done while forging, and iron forging should not be performed otherwise; for the fibers are sure to show when the forging is formed or bent into shape.

Norway iron is tougher than American iron and is very desirable where refining by forging is impos-

sible. A smith can use poor iron and refine it by welding and make sound forgings.

MILD STEEL is treated to an air blast while a molten mass, which renders it homogeneous or fiberless. It will not split like iron or wood when hammered cold. It is often put in parts of machinery because it is tough, stiff, and cheaper than the Norway iron. It is not hardened with heat and water; so the test to distinguish it from crucible steel is to try to harden it. This should always be done at the start to save trouble later.

CRUCIBLE STEEL will harden readily by heat and water. It is melted while made in an air-tight pot. Various grades and uses are given this steel; the lower grades are used in machinery where special hard stiff steel is needed, and the higher grades are called *Tool Steel* and used for fine cutting tools. The test for the various grades is their ability to hold a cutting edge and their performance in actual use. So the smith is careful to notice the brand on every bar; and must have a knowledge of the nature of each brand. One brand only of crucible steel is used here, and we call this *Tool Steel* to give it a shop distinction.

To summarize, the metals used are—

Iron,
Norway Iron,
Machinery Steel, and
Tool Steel.

The preceding notes will hardly be fully comprehended until demonstrated by practice and used as reference in the work that follows.

The beginner should spend about three hours in preparation for the prescribed course, hammering on cold iron until he is able to turn it over and pound on all sides with force and evenness. Take a scrap of round iron and draw it out square and turn it back and weld it into a flat bar; then twist it. Forge a cone on the end and spread it with the cross-pein into an oval or heart-shaped flat (see A, Fig. 1). If the iron splits or gets diamond shape or is rough when complete, it is your fault— try again, and study to correct your mistakes and to overcome troubles.

Twenty of the following exercises are required of each student in forging.

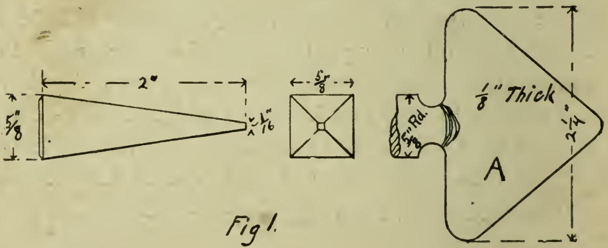


Fig 1.

No. **1.** (Fig. 1.) I. Figure the length of iron required to make it out of a 5/8 round bar. II. Heat to a welding heat on the point. III. Hammer the

point to size first and finish while still at a low heat.
IV. Cut off on the hardy while warm.

Use your left hand skillfully, to keep it straight. The point must be free from splits. All must be done at one heat. Three trials will be given.

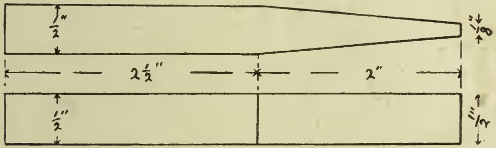


Fig 2.

No. **2.** (Fig. 2.) Stock given, ½"x½"x4" iron.

I. Forge taper like the sketch and square up the ends with the hammer.

NOTE.—Avoid splitting, and pits caused by scaling where not hammered; show smooth, straight and symmetrical hammer-work; test with straight-edge; make cross-lines show distinctly. Use the square iron tongs. Have a small fire.

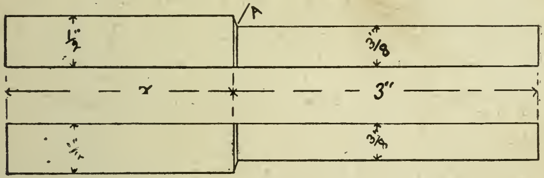


Fig 3.

No. **3.** (Fig. 3.) Stock given, ½"x½"x4" iron.

I. Figure the length of x.

II. Place A on sharp corner of anvil and forge like sketch; hammer on the straight sides.

NOTE.—Avoid flaws at A, caused by changing its position on the anvil. Caliper often. Scale reduces the size of the iron.

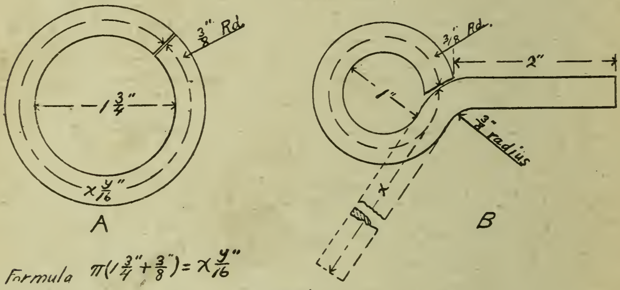


Fig 4

No. **4.** (Fig. 4.) **Bent Ring.** Figure the length of 3/8" Rd. iron at the center as indicated (see A). Stock given.

I. Bend over 1¾" mandrel.

NOTE.—Use a low heat. Do not flatten the ends.

No. **5.** (Fig 4.) **Ring Handle.** Figure length of 3/8" Rd. iron (x+2") as indicated (see B). Stock given.

I. Dress ends and bend as indicated over round corner of the anvil.

II. Bend on 1" mandrel.

NOTE.—Keep it free from scars.

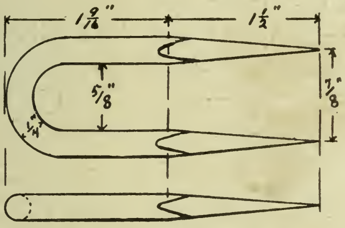


Fig. 5.

No. **6.** (Fig. 5.) **Staple.** Figure length of ¼″ Rd. iron to be given.

I. Draw Out square points and bend over horn and use side of hardy to straighten.

NOTE.—Use welding heat on points, and low heat to bend center. Cool points in water. Must be free from marks.

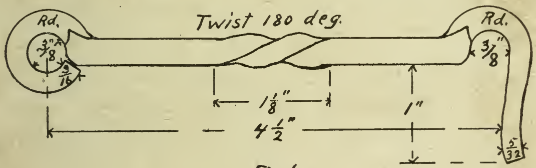


Fig. 6.

No. **7.** (Fig. 6.) **Hook.** Stock given, ¼″x¼″x 8″ iron.

I. After a good eye is made and approved, cut the stock 5″ long from center of eye.

II. Forge and bend hook to be right after twist is made.

III. Twist at low heat.

NOTE.—Study carefully the heating.

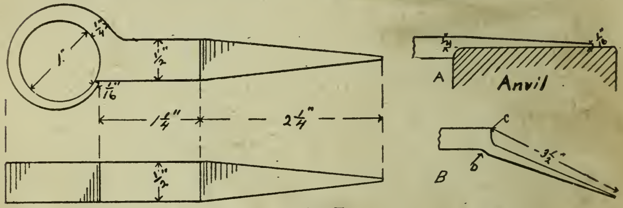


Fig. 7

No. 8. (Fig. 7.) **Exercise.** Use extra length of ¼"x½" Norway iron.

I. Draw on round corner of anvil (see A).

II. Make offset at D by upsetting (see B).

III. Bend over horn.

IV. Cut and forge point.

NOTE.—Avoid nicks at D; make C sharp.

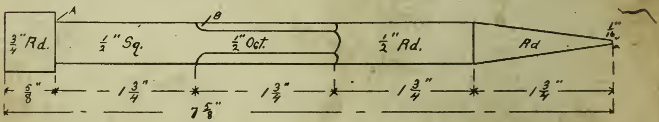


Fig. 8

No. 9. (Fig. 8.) **Exercise.** Use extra length of ½"x½" Norway iron.

I. Upset round head plenty long. Use set hammer and heading tool to shoulder up at A.

II. Start the octagon at B with ½" fullers; hammer to gauge.

III. Draw round part to gauge.

IV. Cut and draw point.

NOTE.—Strike hard on the end to avoid the cup at the end. Keep it central. Everything must be hammered. Take measurements from the end to avoid variation.

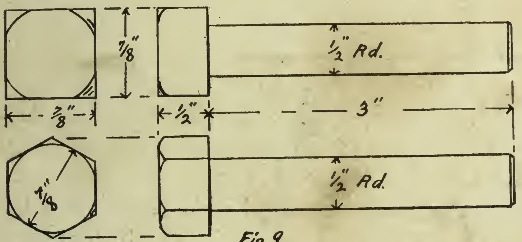


Fig. 9.

No. **10.** (Fig. 9.) **Upset Bolts.** Stock, ½″ Rd. Norway iron.

I. Upset bolt head by hammering on end and finishing in heading tool.

II. Make one square head and one hexagon head bolt.

NOTE.—Keep it always central, avoid getting the head too short, which causes cracks under the head. Keep top round.

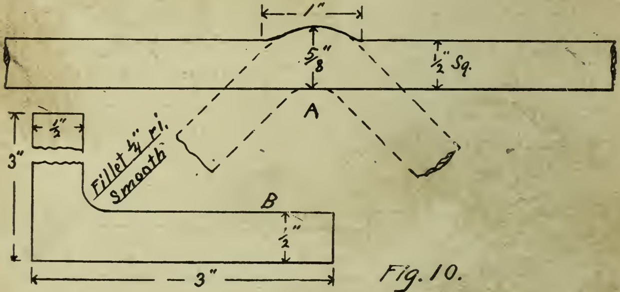


Fig. 10.

No. **11.** (Fig. 10.) **Knee Forging.** Stock, ½"x½" x8" Norway iron.

I. Upset in center and bend as indicated (see A).

II. Continue bending by upsetting (see B).

NOTE.—Nicks on the inside will become cracks. Avoid drawing out sides on the anvil when not desired. Use trysquare on outside.

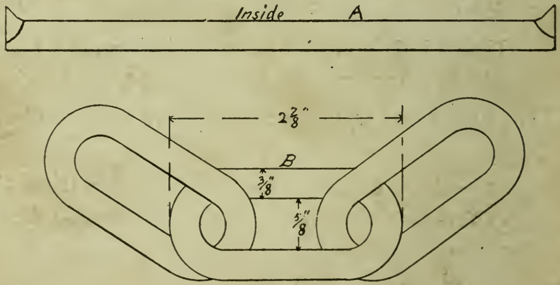


Fig. 11.

No. **12.** (Fig. 11.) **Chain Links.** Stock, 3 pcs. ⅜"x7" Rd. Norway iron.

I. Upset ends and scarf inside corners slightly (see A).

II. Weld in a clean fire, two links; put all together when welding the third.

NOTE.—Make weld at end of links; leave it heavy at weld and round.

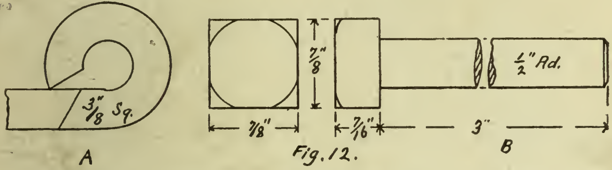


Fig. 12.

No. **13.** (Fig. 12.) **Welded Bolt.** Stock for ring, 3/8"x3/8" iron; for bolt, 4" of 1/2" Rd. iron.

I. Bend and cut ring on hardy (see A).

II. Upset bolt 1/16" about 5/8" long.

III. Put on the ring and weld it square as you go. Put in heading tool for squaring end.

NOTE.—Take the welding heat slow, to give the center time to heat. One heat is enough for the head in (III.); leave a fillet under head, if possible.

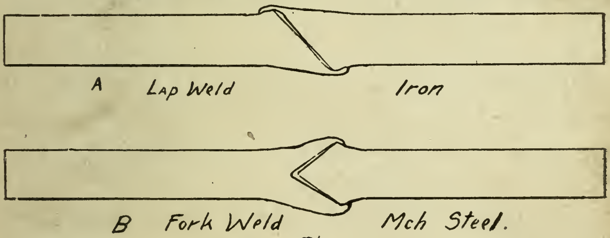


Fig 13

No. **14.** (Fig. 13.) Stock of iron and machinery steel varied in size and shape by the instructor.

I. With the iron, upset and scarf the ends and weld by heating both ends at once and laying together on the anvil and weld with the hammer. If you are slow and only get them stuck—heat again and then weld. (See A.)

II. With machinery steel upset and fork one end as in B and put together tight before placing in the fire for a welding heat.

NOTE.—Much time should be spent at this exercise. Have a clean fire. Too much blast and shallow fires often spoil a welding heat, as it drives the dirt onto the metal. Upset enough to have plenty in welding and still keep the metal full size. Strike hard when welding the center.

Notes on Tool Steel.

Tool Steel is made from the best material and should not be carelessly used. In heating, the fire should be well coked and not hotter than needed to bring the steel to the desired heat; internal strain is caused by fast heating.

There is no need of scaling the steel to heat it throughout; it is well to take time, and yet not best to soak the steel in the heat after it is hot.

Heavy pounding, when evenly distributed, is a benefit to hot steel. To do this, it is best to keep the forging square at first and change to the desired

shape when near its completion. Thin flats should not be hammered on edge, and often we cut off the edge rather than shatter the grain by pounding on a thin edge. In making small tools like a scratch-awl, it is possible to keep the steel hot by hammering.

Hardening and Tempering.

The simple method of hardening steel in water and tempering by heating to the desired color is the only method that we have found necessary for any tool that is used in the machine shop. But we use only good steel of a uniform grade—well forged.

If the instructor will perform the following experiment before the class it will be of great benefit:—Take a new bar of Tool Steel, equal in quality to the Crescent Extra, say 3/8"x3/8"x12", and brighten one side with a file and file notches in one corner, say 1/2" apart, for reference. Now heat this bar nearly the full length so that one end is a welding heat and have the heat gradually diminish to a black, taking notice where the red and black seem to unite. Plunge this rod straight down into soft water, and when cool, take a fine file and notice the following. First:—On the side where the original scale is left you can scratch it. This proves that the scale is oxide of iron and will not harden. Second:—Test carefully the hardness and you will find it hard all along the part that was heated up to the point where there seemed to have been no color; and that within 1/4"

of the end of the hardened steel *it is soft.* This is a valuable part of our test. (A) Steel will not moderately harden—it is either hard or soft. (B) Hardened steel is a constant and a basis to work from in tempering; just as we reckon the degrees of Centigrade from the freezing-point. (C) It is not necessary to heat steel enough to scale it in order to harden it. Our best tools can be finished before hardening. Third:—Break the bar up into small pieces and examine the grain of each piece. The over-heated parts will be coarse-grained and brittle; but it will improve as the place is approached where but little heat was given it in hardening. Also notice that all the water-cracks are found in the part that was very hot.

In conclusion: The lowest heat that will harden tool steel is the best.

NOTE.—It is necessary to harden annealed steel twice before it becomes hardened.

Hardened steel is too hard and brittle for most purposes; so that it is necessary to soften it a little by heat, to suit the varied needs. This process is called *tempering.*

The degree of heat of polished iron, brass, or steel is shown by its color until it is blackened by heat. For our purpose we do not care what degree Fahrenheit is represented by a certain color; but we do know the effect of the heat represented by a certain color on a hardened piece of steel. So that tempering is simply this: Harden the steel by heating it to a low

red heat and plunging into water, leaving it in until it is cooled; polish it on one side and heat it by contact with a hot piece of metal, or hot sand, until the color shows that the steel has become soft enough for the desired purpose. Then prevent its getting softer by cooling it again. The first color noticed is yellow while the steel is yet very hard, but as the color darkens the steel softens; for lathe tools a straw color is needed—cold-chisels a blue, screwdrivers a blue-black. A color-tempering scale for various tools in use can be seen on the shop wall. This scale is taken from Vol. II. of Appleton's Cyclopedia of Applied Mechanics.

In tempering the cold-chisel or lathe tool, it is best to heat the body part a black warm, and the point to be hardened a low red heat.

Harden the part to be tempered in water and when removed the wet should not dry off in steam, for that indicates that the cooled part is being heated very fast, from the body part which is still warm. While it is slowly heating, polish the point and watch for the desired color which indicates a softening of the steel. Redip the tempered part when desired to keep the temper, but do not dip the body until it has cooled beyond the point where it will harden. Skill is required to have the color run slowly, by getting the right amount of heat in the body to produce the color. The slower the color runs the more even will be the temper.

When steel is to be tempered evenly all over, it is first hardened all over, polished, then put in contact with hot sand or iron until the desired color is reached.

NOTE.—Remember that the color of polished steel does not indicate its temper; it only shows a heat, and unless the whole process of tempering is known, the color is of no value; the first color after hardening is the only one of value by observation.

The above will be a foundation for extended study; and special work should be referred to the instructor, whose experience and judgment are needed in deciding special methods; all of which, however, involve the above principles.

Annealing.

Annealing steel is to soften it for easy cutting. After heating to a low heat, put it in a lime-box, or similar air-tight place, to keep it warm for some time, and it will become quite soft, so that threads can be cut on it.

Water Annealing is a method of softening steel by heat and water. When the steel is at a point of heat that is hardly seen in a dark place, it is softened by water, much softer than if it were allowed to cool naturally. This process is used when holes are to be drilled in the end of tool steel forgings or returning lathe centers.

Case Hardening is produced by the application of

cyanide or yellow prussiate of potash on iron or machinery steel while it is red-hot and immediately plunged into water, which gives it a hard coat. This method is used on nuts and screws for machines and bicycles. The success of the operation is indicated by the snap as it is plunged into the water hot. Tool steel is never treated in this way.

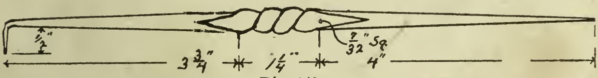


Fig. 14.

No. **15.** (Fig. 14.) **Scratch-Awl.** Stock, 3″ of ½″ Oct. Tool Steel.

I. Draw it out to $\frac{7}{32}$″ square and 5½″ long.

II. Twist it 360 degrees as indicated.

III. Draw each end to a round point $\frac{1}{16}$″ diameter. Grind the point before bending down ½″.

IV. Temper to a straw color on each end.

NOTE.—Grinding, except on points, is not allowed; make corners of twist sharp with the hammer. Show skillful hammering.

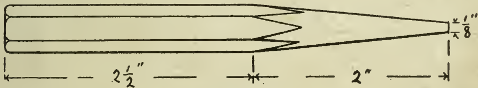


Fig. 15.

No. **16.** (Fig. 15.) **Center Punch.** Stock, 3½″ Oct. Tool Steel.

I. Draw to a square point at a low heat and then change to round.

II. Grind point 60 degrees and temper it dark straw color.

NOTE.—Show hammering, and not grinding.

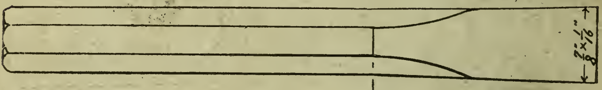


Fig. 16.

No. **17.** (Fig. 16.) **Cold-Chisel.** Stock, 6" of ¾" Oct. Tool Steel.

I. Hammer by hand at low heat, keeping it square for awhile, then flatten. If it is a little too wide when nearly finished, grind it off, rather than strike the thin edge and shatter the grain.

II. Grind the edge 60 degrees.

III. Temper blue and test.

NOTE.—No finish by grinding allowed.

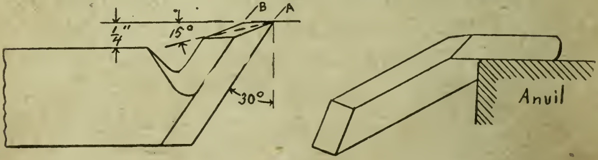


Fig. 17.

No. **18.** (Fig. 17.) **Diamond-point** lathe tool. Stock, ½"x1" Tool Steel given.

I. Forge on corner of anvil as indicated and cut

off point so that A will be ¼″ above top and higher than B.

II. Grind top and front of tool.

III. Temper a straw color.

NOTE.—Test your stock for Tool Steel, if necessary. Use hammer only in forging.

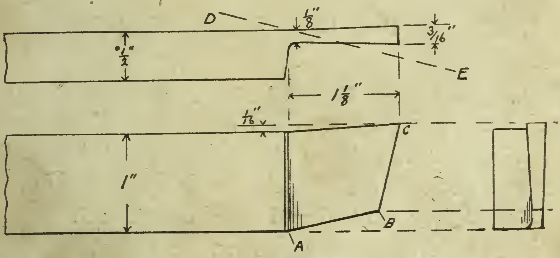


Fig 18

No. **19.** (Fig. 18.) **Cutting-off Tool.** Stock given.

I. Forge with hammer, keeping AB well slanted until nearly finished, then do not strike the edge.

II. Cut off at BC.

III. Grind carefully to leave the point wider than any other part, and sides flaring, so that it will follow its own cut, made by cutting edge C.

IV. Harden the top only and temper dark straw.

NOTE.—If the sides are finished carefully with a hammer, they will need no grinding. If desired, a slant DE may be given.

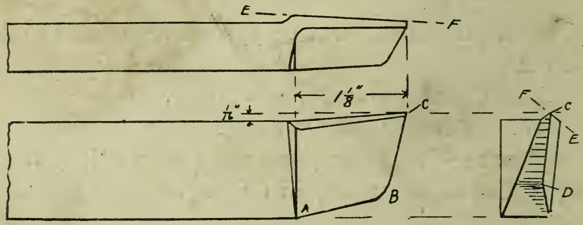


Fig. 19.

No. **20.** (Fig. 19.) **Side-cutting Tool.** Stock given.

I. Forge this tool the same as No. 19, except the cutting edge is on one side EF, so it is left full width at the bottom and flares at CD. Slope AB with hammer and cut off at CB.

II. Grind on top and side surface CD.

III. Temper top to straw.

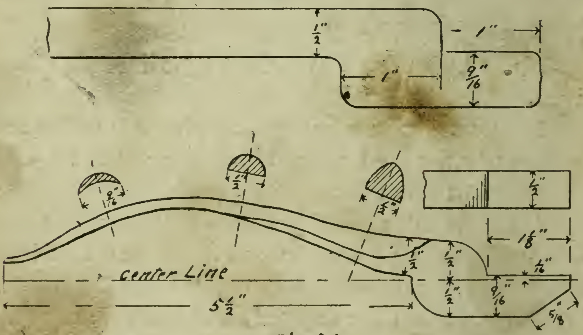


Fig. 20.

No. **21.** (Fig. 20.) **Pliers.** Stock, 2 pcs. ½"x1" x4" Mch. Steel.

I. Test stock and hammer over corner of anvil to general form (see the sketch above the drawing).

II. Finish jaw and round part, then the handles.

NOTE.—Smooth, accurate forgings are necessary; leave handles smooth-hammered; notice their cross-section and position from the center line.

Every student is required *to complete* these pliers.

The test of ability is given in work that follows where no instructions are laid out, and one's judgment is all that is reliable. Students of different courses of engineering could now do special work in their own lines, under the help of the instructor.

Figs. 21 to 25 are only a few of the exercises suggested; others may be seen on the sample-board in the shop.

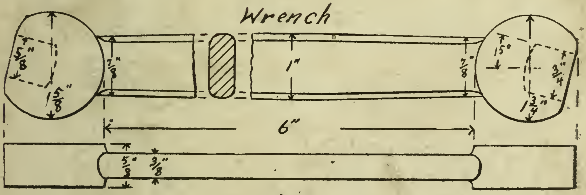


Fig. 21.

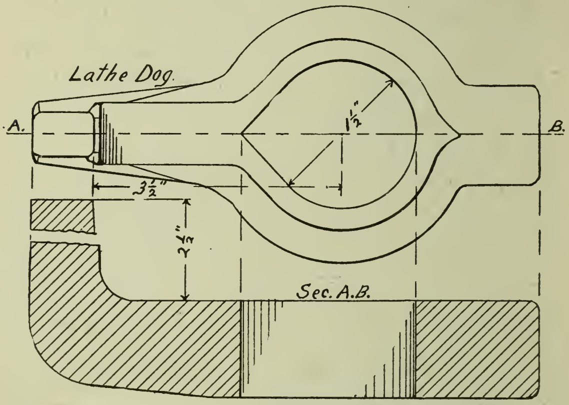


Fig. 22.

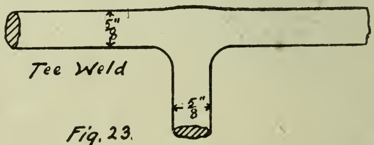


Fig. 23.

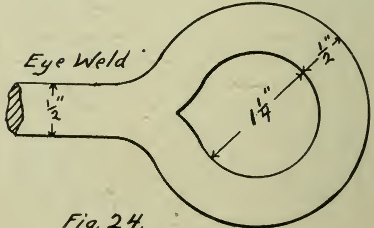


Fig. 24.

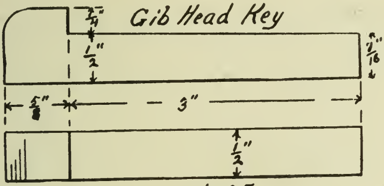


Fig. 25.

CHAPTER II.

Bench Work.

Bench work consist in the use of hand tools and mainly consists in filing, chipping, and drilling small holes with the drill press.

No heat is used as in forging and the metal is reduced by cutting to suit the purpose for which it is made. And yet the cutting done by the file and chisel at the bench can not well be done by the machine tools. Each has its work and usefulness.

Filing, though not hard work, requires patience and attention to style of motion. In one respect, like forging, it is dependent upon the eyes, hands, and judgement; practice in movement is required similar to that in beginning penmanship. Both hands are always used in filing; the right hand is held close to the side with the wrist curved so the file can be moved nearly straight out from the body; the

thumb resting on top of the handle and the end of the handle resting against the palm of the hand; the left hand resting on top of the file, at the end, with the fingers gently grasping the file so that the fore-arm is at an angle of about 45 degrees with the file. The vise should be within easy reach and of a height to permit the forearm to be level and the body erect.

No great pressure is needed on the file in the cutting stroke, for the object of good filing is to produce sraight work, and not to remove metal. Do not raise the file off entire y on the return stroke, but do not drag it back hard. The similarity in movement is easier to maintain than a repeated routine of several movements. When the file is cutting, the student should observe its effect without stopping the file. Adjust the hand to suit, until the desired results are obtained. It is necessary to change the position to make the lines of the filing show plainly and cross-cut each other to prevent filing uneven.

Do not file when you have no knowledge of the effect.

The student should first take a short stroke, and gradually learn the longer stroke in two or three days. Use the rough file to get the work straight; only using the mill file to smooth it up just at the last. It is sometimes best to draw file with the mill file to keep it from clogging up and scratching.

To do this, put the file cross-wise and file both ways with a short, quick, movement. Drawfiling is

not practical and should only be done to smoothen iron. Some kinds of work need not be drawfiled, as the double-cut, rough file will leave it sufficiently smooth. A straight surface is more necessary than a smooth surface and the former should not be sacrificed for the latter. Test the surface with straight-edge and surface plate, or when parallel surfaces are made, test with the calipers by so adjusting them that they are loose in one place and tight in another, for comparison. Do not depend upon the friction of calipers to ascertain variations in the thickness. Take off the wire edge with the file before testing.

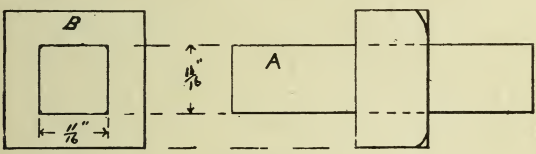


Fig. 26.

No. **1.** (Fig. 26. **Exercise.** Stock ¾"x¾"x3" of iron and a ¾" square nut. Kept in tool-room.

I. Practice filing on the ends of A, using the edge of the file to take off the roughness. Do no drawfiling.

II. File two adjoining sides of A true and 90 degrees, leaving two sides black. Have your work inspected by the instructor.

III. Finish the ends 90 degrees regardless of length.

IV. File the square surface of B true to the surface plate. Grind off any thick scale that might be on the nut; it ruins the file.

V. File two opposite sides parallel and 90 degrees from the face, making the hole central; using the calipers at this place will be quite a study and should be given close attention. The hair-spring screw should be adjusted very freely to assist in their proper use.

VI. File remaining two sides the same; making both diameters equal, all angles 90 degrees.

NOTE.--By filing opposite sides in this way, no great error in the angles can be made, the work will check itself, an imperfect square can be detected and used as well as a true square.

VII. Mark out a $\frac{11}{16}''$ square hole on both sides, with your scratch-awl, making the hole central.

VIII. Check out a rough square file and a parallel three-cornered file, using the latter to finish filing the hole. Keep the walls of the nut parallel and equal; leave the corners a little round like those of the file. Use the calipers to get the walls equal and thus produce a square hole. Inspection.

IX. File the black sides of A to fit in B, and when driving it in lightly, you may be able to improve the hole. A should fit into B in any way. File off the corners of A so they will not quite touch.

X. Polish all exterior parts except the fitting and black parts. Put the emery-cloth under the file

and use the coarse freely to remove the file-marks and polish with the fine cloth. Avoid rounding the corners.

NOTE.—You will notice the black grain of the iron; do not try to work it out.

In this exercise the student should learn to file just where desired and true. All who complete No. 1 well and file well, having a good movement, need not do No. 3.

Call on instructor to inspect each of the ten operations if desired. Always start right and keep right.

The drill press is very easy to manage in the work that follows. The work is clamped in the vise or clamp. Do not try to hold work by hand until your experience will insure success. The drills and the countersinks are checked out of the tool-room. 75-degree countersinks for screws and rivets have an octagon shank. Grind your own drills on the face of the grindstone, holding the cutting edge up and parallel with the axis of the stone and keep it parallel while rounding the heel off for clearance. Make the lips the same length by measurement; but no special gauge is needed for the drills used in the work here given.

Lard oil is found in the large cans and is used in drilling wrought iron or steel, but very little is needed; about three drops placed on the drill about one inch above the work while the drill is cutting

will be all that is needed in drilling ¼″ holes in ¼″ plates.

Use the fastest or first speed for holes up to ¼″, the second for holes $\frac{17}{64}''$ to ⅜″, the third from $\frac{25}{64}''$ to ½″, the fourth from $\frac{33}{64}''$ to ¾″, for all metals except tool steel.

Be careful in using the self-feed, it is quite fast for small drills. The drill should be fed enough to cause the chips to curl. Do not allow the drill to slip and harden the surface to be cut. Have waste handy and keep work clean.

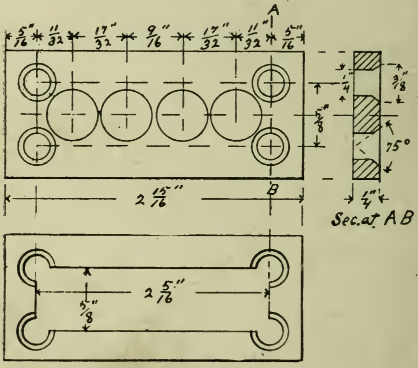


Fig. 27

No. 2. (Fig. 27.) Varified Exercise.

I. Cut off the stock ¼″x1¼″x3″ from a bar of iron.

II. File ends $2\frac{15}{16}''$ long for convenience in measuring.

III. Mark the rectangle and holes to be drilled by pricking the centers with center-punch, then scribe the circles with dividers kept in the tool-room. Put four prick punch-marks on each circle to locate them permanently.

IV. Hold the work in the drill clamp and start the drill cutting, but before it cuts full size, compare the outline of the drill with the circle on the work. If it is not true, it must be moved by punching a hole in the countersink with the center-punch, which will cause the drill to cut more on that side. The drill does not always follow its point and must be thus changed. After drilling and countersinking the holes,

V. Cut out the rectangle; hold in vise and cut center with your chisel so you can get the file started. Chip towards the metal.

VI. File inside to measurement. Do no polishing.

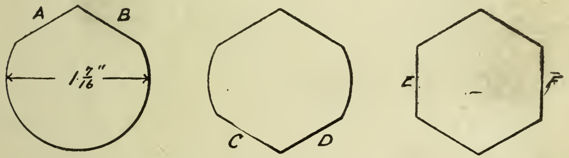


Fig 28

No. **3.** (Fig. 28.) **Quiz.** Time given is three to four hours. Stock, section of steel shaft $1\frac{7}{16}''$x$1\frac{9}{16}$ long, from tool-room.

I. File a true hexagon; file sides AB perfect, then CD parallel to AB, and EF last, using calipers to check errors. Use the special blade of the square. Make perfect as you go. Polish.

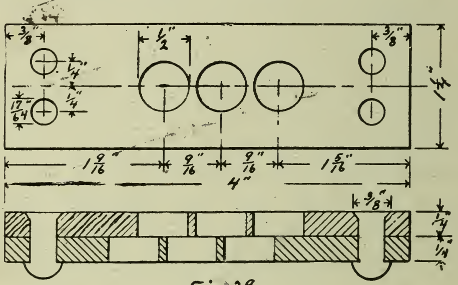


Fig. 29

No. **4.** (Fig. 29.) **Exercise in Close Drilling.**

I. Cut the stock off of bar of iron.

II. File ends.

III. Lay off and scribe holes in one plate as in No. 2.

IV. Start all the holes with the drill. Then clamp both together in drill vise and drill through all the holes; countersink one plate as indicated. Clean well and have them inspected.

V. Rivet the plates together reversed. Make the rivets of ¼″ Norway Iron ¼″ longer than the holes. Use the round pein of the hammer to fill up the countersink and both hammer and rivet-set on the rounded ends. Pound enough to head it well, but not to split the plates.

NOTE.—Let the riveting be purely hammering and do not file or chip the heads.

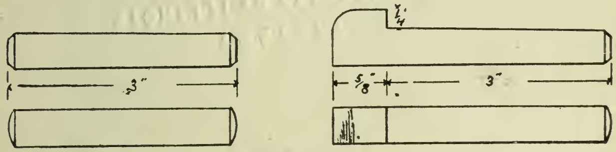


Fig. 30.

No. **5.** (Fig. 30.) **Key Filing.** Stock ½"x½"x3" Mich. Steel from bar or Fig. 25. Keys are parallel and close fitting on the sides; they taper about ⅛" to the foot on top or side which touches the hub only. The widths are made to suit a stock size bar of steel nearest in size to one quarter the diameter of the shaft. But little or no filing is needed on the sides, the bottom is made straight and the top may be made rounding or any shape to fit the taper of the hub when in its place very tight.

I. File key to size by measurement so that it will partly enter into its place.

II. Drive it in lightly, well oiled. File bright spots, and repeat until the bright part extends full length and width; leaving ⅜" projecting to be driven in tight at a future time.

III. File ends like the sketch. Polish ends only.

NOTE.—No draw-filing is needed on this key until at the last touch; file lengthwise with rough file. This work requires about two hours. Find hub and key drift in tool-room.

No. **6.** **Surface Plate.**—Stock given from special soft cast iron.

This exercise introduces chipping with the student's own chisel and scraping to a true surface.

I. In chipping have your chisel about $\frac{1}{16}''$ thick; ground 60 degrees. Do not take off more than $\frac{1}{8}''$ cut at a time. Use a $1\frac{1}{4}$-pound hammer, gripping the handle about 9″ from the head; swing it over the shoulder steadily and evenly, using a movement from arm and wrist. Soft "feeling" taps are not allowed. Hold the chisel loosely and cut toward the center to avoid breaking off the edges of the iron. Take off two cuts.

II. Chip the edges to complete a square.

III. File with the rough file to surface plate. The edge of the file can be used to advantage.

IV. In scraping, grind the scraper as straight as possible on the side of a smooth wheel; whet it on an oilstone until very true. Scrape quite heavy at first, to keep the metal rough until nearly level. Then shorten up the stroke with care to finish well, changing the position often to prevent making vibrations and grooves. When finished, it should touch about half its surface on a dry test surface plate; all the corners and edges must touch.

Be careful to have no dust between the plates, and put one drop of oil on and rub the test-plate with the hand to get the oil off and insure a clean surface.

V. Scrape the edges true; frost them by making irregular spots at regular intervals.

NOTE.—In cutting your plate out of a large plate of cast-iron, drill a series of holes around it, that will cause it to break out easily.

Scraping is the finish given to all planed work of machine tools and engines where true surfaces are needed. Scraped surfaces wear well. Take pride in your chisel.

Insert a brass name-plate in the edge, if you desire.

Wearing a glove on the left hand while chipping is considered wise and good taste.

Chipping an offset on the edges held by the vise will prevent the plate slipping down. Cut cross-wise the vise. Use the heavier vise.

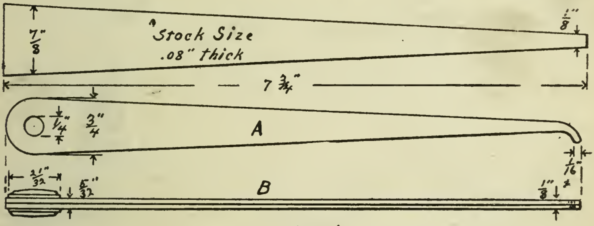


Fig. 31.

No. **7.** (Fig. 31.) **Inside Calipers.** Stock, Tool Steel.

I. Cut stock out on the shears; cut close to the line and do not have unnecessary filing.

II. Drill $\frac{1}{4}''$ hole and file edges like sketch A.

III. Bend points in forge shop.

IV. File and polish sides like sketch B; free from scratches. See that the joint around the hole is parallel and well surfaced.

V. Put together with washers kept by the instructor. See that the machinery steel pin fills the hole in the legs tight. Leave $\frac{1}{64}''$ on each end for riveting. The washers are made concave to spring and take up the wear. Oil the joints. File off the rivet smooth and rounding, polish by hand and then polish to a circular polish by use of the drill-press and a small piece of emery-cloth stretched over a stick held in the clamp.

VI. File the sides of the legs tangent to the end curves, when legs are at 90 degrees.

VII. Stamp your name on the inside, if desired.

NOTE.—Use calipers in IV.

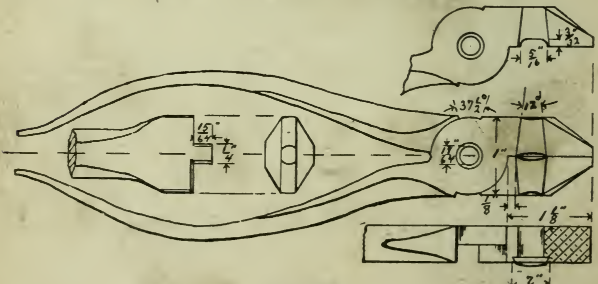


Fig. 32.

No. **8.** (Fig. 32.) **Side-cutting Pliers.** Stock, Fig. 20.

The student is expected to show taste in making these pliers, in things that can not be shown well here. Every student is required to finish them as indicated below.

I. Mark the center line and circles for boring and locate permanent marks with the pick-punch.

II. Drill $\frac{1}{4}''$ hole by resting the forging on a level strip of iron in the clamp. See that the pliers are smooth on the bottom side.

III. Forge a pin-drill from stock kept in the tool-room, finish to size by filing, and temper dark straw. Make it as large as possible to suit the pliers.

IV. Countersink each piece to exact depth, using a parallel block to bore on. Return drill as soon as possible, so others can make one.

V. File carefully to fit them together; file jaw to the center line. Leave shoulders as indicated to open to.

VI. Make cutters as indicated, of tool steel stock kept in the tool-room. Fit them to each jaw, making the dovetail part to suit a three-cornered file. Allow some for shrinking in tempering. File cutting edges 60 degrees and in line with the corner of the jaw, as indicated; score the jaws with a file. Run a $\frac{17}{64}''$ drill through the hole while the pliers are together, so the pin will not bind.

VII. Case-harden the jaws and temper the cutters to a straw-color.

VIII. Oil well and rivet together, striking the rivet lightly to head it without swelling the body. When finished, loosen the rivet over a hole.

NOTE.—A well-forged pair of pliers needs no bright finish on the handles. Polish around the jaws. Stamp your name on the inside of the handles, which will prove the maker. Test the cutters with an 8-d. wire nail.

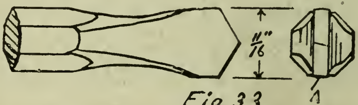


Fig. 33.

No. **9.** (Fig. 33.) **Ratchet drilling.** The ratchet-drill is a tool used to drill holes by hand where the power-drill cannot be used. The "old man" is the frame-work that is put up to hold the "ratchet" and drill.

I. Forge a drill out of stock kept in tool-room. Temper to dark straw-color. Finish by grinding on the stone.

II. The iron given by the instructor to be drilled can be clamped in the vise and the "old man" clamped on to it.

III. Use no oil on the drill when drilling cast iron. Place your thumb so the edge of the drill touches it as they pass when turning; if one side

swings out more than the other, your drill point is not central and will cut too large. Grind true. The rounded edges at A will be a benefit in this respect.

NOTE.—This exercise can be done in two hours. Students who have previously done this work, and who can pass an oral examination upon the subjects, are excused from Nos. 9, 10, and 11.

No. **10. Pipe-cutting.** This work is intended merely to show the method of cutting small pipe by hand.

The nominal measurement of pipe is taken on the inside. The thread is cut taper of ¾″ to 1 ft., and should be tight on the end of the pipe and never allowed to go in to the shoulder of the thread. Cut the thread to fit the fittings (ells and tees) and adjust the die to suit. The marks on the die for standard size may not be correct. Cut all at one cut, using lard oil; the pipe should just come through the die. Be sure the guide fits well.

I. Cut one thread on a 1″ pipe.

II. Cut it off three inches long for a nipple.

III. Cut threads on the other end by holding the nipple in a holder. File off the burrs and give it a neat appearance. This is a short exercise.

No. **11. Babbitting.** Provisions are made to babbitt two boxes which are made in halves.

I. Cut out the babbitt, running a narrow (cape) chisel lengthwise through the babbitt at the bottom. Clean out the retaining-holes.

II. Support the shaft on blocks so that it is central with the parting.

III. Putty up around the ends; cement the putty to the box and shaft with fingers, but be careful not to crowd it in under. Put card-board covers on the parting, leaving large vents and pouring holes.

IV. Add a little babbitt to what was taken out and melt slowly in a ladle until a soft stick will smoke when touched to it. Pour into the box as fast as it will take it; keep the face at a safe distance.

V. Take out the shaft and scrape the sides of the babbitt so the shaft will lie on the bottom and turn easily. Boxes should never touch hard on the sides.

VI. Put the shaft back and put the cap in place with liners of card-board between, to be removed or reduced when necessary to take the up wear. Putty up the ends, leave vents, and put a high pouring-spout of putty on top. Pour as before.

VII. Scrape the cap, drill oil-holes and cut oil-grooves.

VIII. Increase or reduce the liners so that the cap can be tightened and still have the shaft a neat fit.

The cap and box are sometimes poured at the same time with liners between, cut to allow the metal to pass and still easily break and allow them to separate.

NOTE —Consult the forge instructor about melt-

ing the babbitt. Only certain forges are used for this purpose.

It is often necessary to warm the shaft to keep the metal from chilling in rough waves. Sometimes a thin layer of paper on the shaft will insulate it and cause the metal to run smooth. Oil is used for this purpose. In babbitting solid boxes, white lead put on the shaft as a paint will insure good work and give room for removing the shaft, which is done at once.

This completes the work given on this subject at this time.

The study of construction of machinery by hand in a technical way is given in the class-room later. But the student is asked to study the Appendix with a view to using correct names for some of the common articles in the shop.

Students who have time and who stand well in their classes are given use of the wood tools and may make things of their own design, if the design is approved by the instructor.

CHAPTER III.

Machine Tool Work.

The work of machine tools consists in cutting the metal by tools which give it geometrical forms and shapes.

The machine tool is an instrument of great pre-

cision, yet good work will not be performed unless it is intelligently operated.

The writer does not wish to exhaust the capacity of machine tools or any one of them, nor to take up in detail each feature of every tool; but rather to show the operations of lathe-work, which will be uniformly taught and similar, until sufficient knowledge is obtained to enable the student to branch out to other tools and perform special work which will be put to some good use, either by itself or collectively in the machinery which is built by the students.

The lathe is constructed and operated on very simple principles and becomes more and more complex in its results the more it is used and studied. It is capable of doing the most of the work in building machinery and the student is expected to devote the most of his time to the study of the lathe; not only to manipulate the various movements with judgment, but rather to produce true work under all conditions, and make good fits.

The student is given a 14″x6 ft. engine lathe to study and look over with a view to answering the following questions to the instructor: What is the live spindle? Tail-stock spindle? How are the centers extracted? When is each center considered true? What is the chuck; faceplate (how removed); back-gear; single gear; lead-screw and half-nut; straight- and cross-feed; compound-rest?

The following general terms are used: "Rough-

ing-cut," is to cut the metal to nearly its desired size or a cut for removing metal only. "Finishing-cut," for finishing. "Facing," is cutting cross-wise. Trueing-up," is to place the work in the lathe true with the parts which can be turned but little, or not at all. "Centering," is to put the cone bearings in the work for the centers. "Drilling," is done with a drill; "boring," with a tool; "reaming," with a reamer; "threading," or to cut thread, should always be done with a single-pointed tool.

The modern method of standardization is used more in lathe-work than any work of the shop. Standard reamers are provided which are used to ream holes after boring, to produce a standard hole. Standard plugs and collars are kept in the tool-room which conform with the reamers in size. The workmen use the plugs to compare with size of the work, and the collars (called gauges) to make the final test of size.

The cutting speed varies slightly with different metals and depths of cut. Fifteen to twenty feet per minute will be the limits. Very often, time can be saved by an increase of the feed rather than the speed of the metal. For 1″ round iron and steel use the slowest single-gear speed. Close observers soon learn to judge the speed by the passing metal. Spots should be easily seen.

The lathes are oiled once a week, by a man in charge. The student is expected at the start of each

day to clean off the V slides for the carriage, and oil them with machine oil; then see that the change gear are disengaged and the lead-screw free from the half-nut. Turn the lathe by hand to be sure of no other trouble. Be careful in the use of feeds to be sure there are no obstructions. Never stop and leave a lathe with a feed connected. When stopping a cut, always stop the feed before stopping the lathe.

Use lard oil sparingly when cutting-off, drilling holes and cutting threads.

Use water on wrought-iron and steel to take a smooth cut; add 2 grains of sal-soda to keep it from rusting.

Nothing need be used on a roughing-cut unless it is very heavy, and then water is applied to keep the tool from smoking.

Never use lard oil for turning.

The cutting-off tool should not be used at a greater distance from the chuck than 1½ times the diameter of the iron cut. The metal is liable to bend at a greater distance.

The only tools that must be placed level with the center are those that go to the center, like the cutting-off and side tools. The diamond-point should be above the center to give it a freer cutting angle (called "more rake") and to make it nearly tangent to the metal and lessen the liability of breaking the point off. However, should the tool become tangent, the tool will crowd away and then dip in again, mak-

ing the surface corrugated at irregular intervals. In grinding, be careful to keep the tool in its original shape so it can be placed above the center and not be tangent; grind the cutting edge as shown in Fig. 17.

Every student must use his own tools. When they are used up, forge them again.

No. **1.** I. Put on the 4-jaw chuck; chuck a bar of 1″ Rd. iron allowing $1\frac{3}{4}$″ to project. After grinding the cutting-off tool as in Fig. 18, practice cutting off the rod into pieces $\frac{1}{8}$″ long. Use lard oil, drop at a time, every third turn, but in the proper place. See that the disks are cut true. Have them inspected.

II. Cut down the bar as small as possible with one cut of the diamond point, using the self-feed; cut off two disks from the cylinder thus turned; they should be reduced to $\frac{3}{4}$″ at least. Inspection.

III. Cut off stock for No. 2, $6\frac{1}{32}$″ long.

IV. Chuck this piece again; drill centers in the ends. First start a countersink for the drill by use of a special tool on the tool-board. Second, drill a $\frac{7}{64}$″ hole, $\frac{1}{4}$″ deep. Third, countersink 60°, with a half-center, to $\frac{3}{16}$″ diameter.

Note.—In IV. use the fastest speed. The chuck jaws can be set close by the rings on the face, and still closer by trueing up after starting by the mark of chalk. When once set, they need not be changed if only two jaws are moved. The independent-jaw chuck is used for lathes, because it can be screwed very tight, also it is adjustable to the unevenness of

the work. In this work tighten it all you can; it will not break. If the work is loose in the chuck, there is trouble at once.

Study your work; be deliberate.

No. **2.** In preparing the lathe for this work, remove the chuck by using the back-gear to give power, and a block of wood between a jaw and lathe bed. The single-gear can then be replaced on the slowest speed and the lathe run backwards. Hold the chuck firmly by hand to keep it from striking the bed. Do not turn the chuck over on its back, for the chips will fall into the thread and cause trouble. Start the face-plate by hand; never while the lathe is running.

The center hole must be cleaned out and the sleeve cleaned inside and outside, and the center cleaned. Dirt in these places causes the center to be out of true, and the work to be excentric, which will be noticed where the cuts meet.

The centers are all kept true by grinding and will be true in their place when properly cared for. The live center is tested while running, with the work in place without a dog; hold it from turning by hand and put a tool close to it; if a movement is not observed, it is true.

Strictly speaking, it is impossible to keep this center perfectly true and yet remove it at will. The lathe-hand who knows this can so do his work that

the effect will not be injurious if the excentricity is but little.

The tail-stock center is not always left just where it should be, but each student is responsible for his own work. A mark is placed on the slide to assist in setting it straight, but the surest method is to observe the results of the tool on the work. After taking a cut, draw the tool across and scratch a line to see that the tool has cut properly, then caliper the work to test it for straight. To move the center, loosen the main bolt before adjusting the screws. After a straight trial cut has been taken, the lathe is ready for the finishing cut. This is not as difficult as might be expected.

Always make these tests before starting your work of the day; running the tool along close to a finished job will be all that is necessary, generally speaking.

I. With the work on centers, dog in place, face up the ends with the side tool (Fig. 19) making the length 6″. To cut off the burr that is left close to the center, either back off the center to make room for the side tool or put the 60° half-center in as a center, which will allow the tool to do the desired work.

RULE.—The ends must always be faced to the length, the first thing, on every piece of work.

Do not attempt to do *any* work on centers with-

out facing the ends on centers properly drilled; the ends cannot be faced true in the chuck.

II. Take roughing cut to $\frac{31}{32}''$ diameter.

The diamond point should have a flat on the point about $\frac{1}{16}''$ wide to prevent cutting ridges.

III. Turn the shaft to $\frac{15}{16}''$, using soda water for a finish. Compare the size with the plug or gauge, kept in tool-room, allowing about .001″ for polishing. Do not try to take a number of very fine cuts.

IV. Place the belt on the fastest speed and loosen the center. Polish by holding the emery-cloth in the hand; caliper often to find where polishing is needed to allow the collar gauge to fit neatly. Inspection.

NOTE.—No filing is allowed. It is a failing of most students to polish too much where not needed. In case the first piece is spoiled, the chuck need not be replaced to cut off a new piece. Saw it off and locate the centers by a punch, test by chalking on centers, then drill on centering machine or drill press. This way is the most practical way of centering where $\frac{1}{16}''$ stock is to be removed.

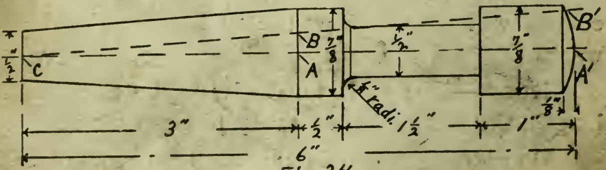


Fig. 34.

No. **3.** (Fig. 34.) Stock used, No. 2.

This exercise is intended to give the student practice in close measurement and detail work from a sketch. None but first-class work will be accepted.

I. Turn as in No. 2 to fit $\frac{7}{8}''$ gauge. Inspection.

II. Round the end by changing the position of the side-tool, leaving a series of small flats that can be easily polished off. Use water. This can be done by eye only; the curve is regular, not a round corner.

III. Cut out groove roughly with the diamond point; then finish the $\frac{1}{2}''$ part with cutting-off tool, the face with a left-hand side-tool, and the fillet with a round nose tool. Make the fillet so a $\frac{1}{4}''$ rod will lie in the proper place.

In finishing cylinders, tapers or a face, a tool point carried by the lineal movement of the slides gives the best results. But when roundings or fillets are made, the operator must depend upon the shape of the tool point and the sight to get the required shape.

IV. Place the dog on the finished end with brasses which are in tool-room. Set the lathe approximately for the desired taper by measuring the offset of the tail-stock. This offset is figured by use of similar triangles. Draw line CB′ through the center and parallel to the taper side. Then AB will equal $\frac{3}{16}$ and A′ B′ is the desired measurement. Then CA : CA′ :: AB : A′B′; substituting we have

$A'B' = \frac{CA' \times AB}{CA} = \frac{3}{8}''$. After moving the tail-stock and roughing off the taper, before finishing, set the tool at the end and cut to the right size. Loosen the center and move the tool over past the line AB, replace center, and notice the position of the tool when at AB. Move the tail-stock if necessary and try again. The latter method is the surest and can always be used. It is modified by placing a scale between the tool and the work as a constant, removing or replacing at will, without loosening the center.

A special gauge is provided for a final test for taper and size. To test a taper, put on three longitudinal lines with chalk, and exert a side pressure while turning about one-third around, back and forth. The chalk will not be rubbed off all around, where the fit is loose. Inspection.

NOTE.—Unless the tool for turning taper is level with the center, the results will not be as expected.

V. Polish at high speed, keeping all the corners distinct. The round end can be polished crosswise, by hand, to remove the ridges, then polished on centers.

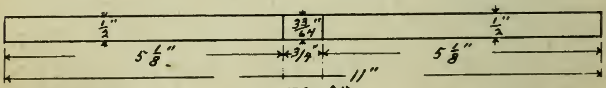


Fig. 35.

No. **4.** (Fig. 35.) Stock used is $\frac{5}{8}$ Rd. Machinery Steel.

This exercise is given to show the spring of the metal away from the tool.

In turning No. 3 the work was quite stiff and no difficulty of this kind was experienced except by close observation; and too often the tool is ground very wide on the point in order to make it cut smooth. A wide tool is a detriment to true work; it increases the amount of linear pressure and causes the work to spring away from the tool.

In No. 4 the diamond point is used and must be ground so that it has only $\frac{1}{32}''$ flat surface on the point, and even then the shaft will spring away from the tool and the tool must be fed in by hand to keep the shaft parallel.

Take the front corner of the tool off with an oilstone; have a sharp cutting edge.

I. Saw the stock off and drill the centers after they are located to suit the bends that may exist in the shaft. It is better to have it true in the center than on the ends; the ends can easily be turned while the middle will spring away from the tool and make it hard to be turned true.

II. Remember to face the ends.

III. Take two roughing cuts from both ends, leaving $\frac{1}{64}''$ to finish. Follow the tool with calipers and feed the tool in as the shaft springs away.

IV. Regrind the tool and take the finish cut in the same way, using soda-water.

V. Use a 10″ mill file to smooth off the steps or irregularities. "Speed up" and loosen the center and oil it. Hold the file to point 10 degrees to the right of a right angle, and push it slowly ahead. Touch the shaft lightly and evenly. Caliper often. Filing is not done to remove metal that could be turned; it is done to smoothen work. Yet it is very impractical and there is liability of filing the shaft out of round.

VI. Polish to fit ½″ gauge, and measure the center part.

NOTE.—Finish without filing if possible. The speed for this is faster than that for No. 2.

The following rest is used to follow the tool, but is not needed at this time. It is especially adapted to cutting square top thread, after the shaft is finished.

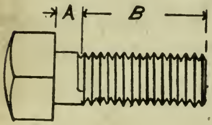


Fig 36

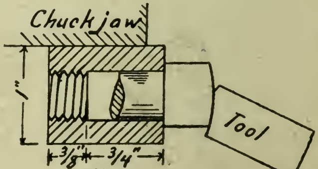


Fig 37.

Diameter of Screw.	Number of Threads per Inch.	A	B
$\frac{5}{8}''$	11	$\frac{3}{8}''$	$\frac{7}{8}''$
$\frac{5}{8}''$	11	$\frac{3}{8}''$	$1\frac{1}{8}''$
$\frac{5}{8}''$	11	$\frac{1}{2}''$	$1\frac{1}{4}''$
$\frac{5}{8}''$	11	$\frac{1}{2}''$	$1\frac{1}{2}''$
$\frac{5}{8}''$	11	$\frac{3}{4}''$	$1\frac{3}{4}''$
$\frac{5}{8}''$	11	$\frac{3}{4}''$	$2\frac{1}{4}''$
$\frac{1}{2}''$	12	$\frac{1}{4}''$	$\frac{3}{4}''$
$\frac{1}{2}''$	12	$\frac{3}{8}''$	$1\frac{1}{8}''$
$\frac{1}{2}''$	12	$\frac{3}{8}''$	$1\frac{3}{8}''$
$\frac{1}{2}''$	12	$\frac{1}{2}''$	$1\frac{1}{2}''$
$\frac{1}{2}''$	12	$\frac{1}{2}''$	$2''$
$\frac{7}{16}''$	14	$\frac{1}{4}''$	$\frac{3}{4}''$
$\frac{7}{16}''$	14	$\frac{3}{8}''$	$1\frac{1}{8}''$
$\frac{7}{16}''$	14	$\frac{1}{2}''$	$1\frac{1}{4}''$
$\frac{7}{16}''$	14	$\frac{5}{8}''$	$1\frac{3}{8}''$
$\frac{3}{8}''$	16	$\frac{1}{4}''$	$\frac{1}{2}''$
$\frac{3}{8}''$	16	$\frac{1}{4}''$	$\frac{3}{4}''$
$\frac{3}{8}''$	16	$\frac{1}{4}''$	$1''$
$\frac{3}{8}''$	16	$\frac{3}{8}''$	$1\frac{1}{8}''$
$\frac{3}{8}''$	16	$\frac{1}{2}''$	$1\frac{1}{4}''$

No. **5.** (Fig. 36.) **Cutting thread** with a single tool in the lathe is the only way to get the work true, and it is often just as necessary to have true threads on a piece of work as to have the remainder true. The student should be able to cut thread with ease and certainty; he is expected to make 18 of the screws given in the list selected by the instructor, and should be able to cut one perfect screw every

hour without spoiling any. These are standard screws with 60-degree threads, which should not be quite sharp; the screw is turned a little small to allow for a slight flat on top; $\frac{1}{64}''$ small for a $\frac{1}{2}''$ screw is about right.

The smooth part "A" is made the size of the threads also. The head is made of square iron or bright rods, $\frac{1}{8}''$ larger than the size of the screw. The ends are slightly beveled to preserve the threads.

Use the chuck and keep the work up close, put the head of the long screws in the chuck and draw them out to cut off behind the head. If a center is used, be careful to drill the center properly.

See that the head is faced square.

Grind the thread tool by the center gauge, a little sharper if anything. Set the tool by the gauge and level with the center.

In placing the change gears in position, make all screws secure and yet allow the idler to have play so you are certain the teeth are not crowded together.

Use lard oil in cutting. Withdraw the tool before stopping or reversing the lathe. Replace it again before starting the cut. The cross-feed handle can be replaced to its former position by observation of the marks on the micrometer. Adjust the desired depth of cut with the compound rest.

When cutting heavy at first, the tool lags back longitudinally by reason of the strain, so that the front side only will cut when taking light finishing

cuts. This leaves the one side of the thread rough and the tool must be moved by a light blow on the side, so it will cut on both sides.

In cutting long, slim screws, it is best to move the tool and cut on one side at a time.

In this work the ends will be largest, due to the spring.

The screw gauge should fit close and turn by hand.

File off the burrs at both ends.

The head can be rounded by slanting the tool after the head is partly cut off. Put on water for a finish just as it drops off.

Fig. 37 shows a method for rounding the heads where the first is not successful. The holder is made in the chuck each time it is used and should not be removed till all the screws are finished. A tool can be ground to round off the head in one operation.

The commercial standard for the number of thread per inch is as follows:

Size of Screw	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1″
Thread per inch	20	18	16	14	12	11	10	9	8

Sometimes 13 threads per inch are used for ½″ screws and bolts.

Common bolts are made $\frac{1}{32}$″ above the size because of the roughness of the iron. So there is a distinction between bolt taps and hand taps. All screws are made for the hand tap size, which is even

size. The hardened and polished nuts used in machine construction are hand tap or standard size. The blanks are cold punched.

No. **6.** It is here intended to give a problem in thread-cutting similar to that which is found in practice, and show one of many such schemes.

Pipe-cutting can be done to an advantage in an engine lathe; by chucking one end of the pipe on the inside, so that threads can be cut on the outside; allowing the long end to extend out over the lathe, resting on rollers or blocks, which are firmly fastened to the lathe.

The student, however, will be given a pipe that is of convenient length. The pipe-center can be used to support the end.

I. Chuck the pipe as above mentioned, leaving $\frac{1}{4}''$ or $\frac{5}{16}''$ at the end for a thread tool. Cut off a nipple to length given by the instructor.

II. Set the compound rest to cut $\frac{3}{4}''$ taper to 1 ft. on the end in the chuck, and turn the end to measure one of the following sizes, $2\frac{13}{16}''$, $3\frac{7}{16}''$, $4\frac{27}{64}''$, $4\frac{59}{64}''$, $5\frac{31}{64}''$, $6\frac{17}{32}''$, which represent the various sizes of pipe. Be cautious in measuring not to spring the calipers. The cut should be run out until it cuts half of the black away.

When setting the compound rest, measure from the side to a straight-edge held up from the edge of the carriage. Set it $\frac{3}{16}''$ to $6''$.

Take notice of the speed.

III. The compound rest is only used to give the pipe the desired taper and can not be used in cutting threads.

Cut the thread by starting the tool in while the lathe is turning, and gradually feed in as it advances along the taper, until the thread is sharp and evenly cut. Use one side of the tool at one time while finishing. File off burrs. All pipe above 2″ have 8 threads per inch.

Do not leave unfinished work in the chuck until the next shift come on.

IV. Cut the thread on the other end in the same way. Start the lathe on single gear and set it true by eye. The thread can be excentric slightly, but must be true longitudinally. Set the end in the chuck first, then strike it with a hammer to true up the thread.

Notes on Cutting Thread.—When the lead-screw has the same thread per inch as the thread to be cut, the lathe need not be reversed and the tool will be right at any place. It can be returned by use of the half-nut. When the thread on both are not the same, the tool can be moved just 1″ or 2″ in this way. When both threads can be divided by 2, then the tool will come right every ½″ along the lead-screw. To do this the lathe must be stopped and the distance measured, but it soon becomes an easy method and is very useful in cutting a long thread at a slow speed.

Figuring the number of teeth in the gear on the

spindle and on the lead screw is a very simple operation. They are inversely proportional; *i. e.*, the spindle gear is to the lead-screw gear as the number of threads per inch on the lead-screw is to the number of threads to be cut. The unknown gear is usually the one on the lead-screw. When compounded gears are introduced between these two gears, the drivers are multiplied together and considered as a spindle gear and the driven as a lead-screw gear. When one or a series of idlers are placed between, no change is made in the proportion.

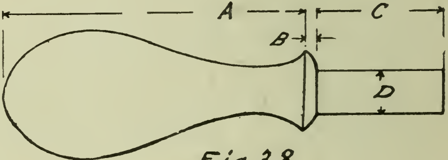


Fig. 38.

Number of Handle.	A	B	C	D	Stock Size.	Time Allowed.
1	3 "	$\frac{1}{4}$"	$1\frac{1}{4}$"	$\frac{7}{16}$"	$1\frac{1}{4}$" Rd.	5 Hrs
2	$2\frac{1}{2}$"	$\frac{3}{16}$"	1 "	$\frac{3}{8}$"	1 " Rd.	$4\frac{1}{2}$ Hrs.
3	2 "	$\frac{1}{8}$"	$\frac{3}{4}$"	$\frac{5}{16}$"	1 " Rd.	4 Hrs.

No. **7.** (Fig. 38.) **Curve Work.** Lathe Handle. Made from Machinery Steel stock, on centers. Selected by the instructor.

The shape of part A can be taken from the lathe handle in use.

I. Saw off and center the stock. Face the ends to right length.

II. Take roughing cut all over, leaving plenty for the dog on D.

III. Locate and turn places on handle as points to turn the curve to. Use a broad tool to finish the convex part, the ridges left can be filed off.

Use a hand tool or scraper on the concaved part; put up a rest (a tool) and turn at the same speed as other tools.

IV. After all the ridges are removed, polish, by use of emery-cloth on a stick used as a lever over a rest. Keep the emery moving to avoid cutting rings. Do not put on fine cloth until all the marks are removed.

NOTE.—Leave D $\frac{1}{32}''$ above the size and unfinished, to be fitted.

None except first-class work will do.

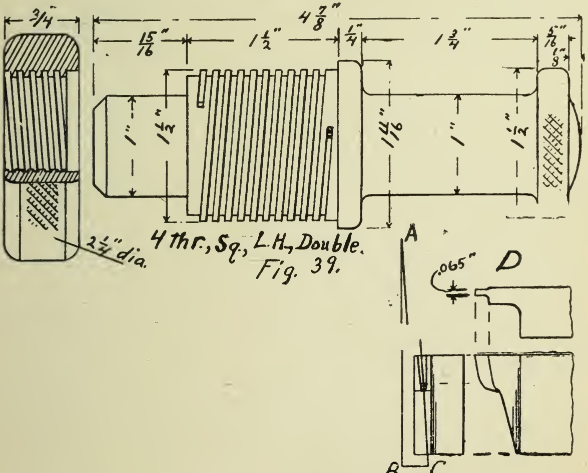


Fig. 39.

No. **8.** (Fig. 39.) The object of this exercise is the study of cutting special thread, both inside and outside. Also of details which are shown in the sketch and not indicated by measurement.

The stock is $1\frac{3}{4}''$ Rd. Machinery Steel and a cast-iron nut. Sometimes scraps are used.

This work must be neatly done; all the points mentioned in the previous work must be observed.

Use the back-gear and take large cuts where possible; have the chips curl up nicely.

Make your own thread tools out of stock from the tool-room. File it to its exact size and shape, after forging. Temper to dark straw without scaling it and it will be ready for cutting. Give special attention to the clearance slant. Make it very short; a long tool springs out of time and makes an irregular thread.

Cut the space .005″ wider than the thread. The sketch at D shows the tool and clearance to allow. AB represents the circumference of the screw, BC the travel of the tool in one turn, AC shows the slant of the thread at the cutting edge.

Keep enough metal on the ends of your work so the dog can be used without brass. If your dog slips in cutting the thread, the tool will be broken; have everything firm.

Cut square thread with light cuts so the sides will be true and smooth. Finish one thread, then change the half-nut of the lead-screw and cut the

next; see that the tool is central before cutting. Measure the depth with calipers with thin points.

As the nut will be the first inside work of the student, it is well to mention a few things about chuck work that will apply to all work of this kind. First: True up the work, in the chuck, by the part not finished, or that has but a little stock. Second: Do the heavy cutting all over the parts to be turned while in this position, before finishing any part. Third: Do not remove the work from the chuck until *some parts* are finished that can be used to hold the work true again; *i. e.*, should the outside of a pulley only be finished when removed from the chuck, it cannot be put back in the lathe true to bore the hole, while if the hole is finished, it can easily be placed on a mandrel on centers to turn off the outside. In No. 8 the thread, counterbore and face must be finished before removing it from the chuck. Then it is placed on the screw and finished outside. Fourth: Take off the sand with a round nose tool before using a drill or finishing tool. Fifth: Drills may be used to remove metal from the holes, but the boring-tool must be used to make the hole true before reaming to standard size. When holes are a special size, like No. 8, the reamer cannot be used, but must be bored to the size with measurements carefully taken with calipers. Reamers should not remove more than .01″. It is a good practice to set the inside calipers to a gauge rather than a scale.

In this case the insides must be set to the outside thread calipers, and a working fit made before starting to cut the thread.

Cut light with the thread tool; the cast iron is severe on the sharp corners.

Practice nurling on a piece of scrap before attempting to do the nurling required.

Polish as usual.

This exercise is difficult, but can be well made by every student. It is of great value to the student and will speak for itself when completed.

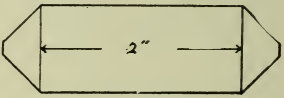


Fig. 40.

No. **9.** (Fig. 40.) Exercise in making a drive fit, by use of outside and inside calipers.

In the previous work measurements were made by comparing the size of the work with a standard gauge by use of the calipers and collars. In this case no comparisons are allowed and calipers only are used. A hardened block of steel to which the fit is made is kept by the instructor and the size must be taken from it with insides, and then the outsides made to fit, and the work to the outsides.

This is an important and very practical operation and will need close study.

I. Set the insides in the hole so carefully that

moisture on their points could be detected by feeling. Keep one point still while moving the other lengthwise and crosswise until the exact diameter is found. Do not spring the calipers together by holding too tight.

II. Hold one point of each calipers together and adjust the hairspring until a slight contact is made on the largest size found on the insides. Hold one leg only, to avoid springing. Do not lay them down to do this; the largest place can not be found in that way.

III. Use a scrap piece of steel and turn it in the chuck like the sketch, to a drive fit with a hand hammer. Leave the surface as smooth as the tool will make it, and straight. The diamond-point will do all the cutting. By moving it back and forward lengthwise, both ends can be made. The points are merely for convenience in driving.

The instructor will try the fit. Three trials will be given. Most students need but two trials.

NOTES.—In repair work the above method is often the only one possible, and yet not every workman can make a good fit at will.

To those who inquire as to the amount to leave for a drive fit, the writer will say: Make it the exact size; when a work fit is made, let the insides be slightly loose, in the hole. For a shrink fit, allow just enough to make it impossible to drive. Driving cuts off the metal, but shrinking is to enter the shaft

loosely while the hole is expanded by heat, and no metal is lost; the result is a very tight fit. Often a mistake is made by leaving too much for a shrink fit, which strains the metal nearly to its elastic limit.

This completes the exercise work, which usually occupies two years.

The student is now given parts of work that is put in some machine or tool which is in process of building. The following are some things that have been built from the rough in this way: An 8″x10″ engine; 16″x6 ft. engine lathes; 20″ drill presses; a 16″ shaper; 12″ emery grinders and countershafts; a 50,000-pound transverse testing machine. All of these are in use here. Much apparatus has been made for the various laboratories.

The cast-iron parts and drawings are given to be machined and fitted up. All the machine tools are now used as the work is carried on by the student.

It is impossible to give the needed instruction here, but a few suggestions are all that can be comprehended until the actual work is done. The writer has found that when the exercises have been completed, the student will be more careful and handle other machine tools with the judgment necessary to enable him to be trusted with work of the above sort.

The following are a few general instructions:

I. Turn everything on centers where it is pos-

sible, leaving good centers in the work when finished.

II. In taking longitudinal measurements, start from a finished face or center line, just as you do in making the drawings.

III. Do not file cast iron to prepare it for polishing; the file scratches. A broad-tool finish is not desirable for polishing. Do as much as possible with a well-formed pointed tool.

IV. Hard cast iron can best be turned or planed with self-hardening steel, ground round or nearly thread tool shape, placed slightly below the center.

V. Use a driver, and not a dog, on large turning, such as pulleys.

VI. Small keyseats are often cut in the lathe by moving the tool by the hand gear while it is held in the tool post. Large ones are cut on the planer or shaper. The shop equipment does not consist ot a keyseater.

VII. All lathes are provided with large face-plates with slots and holes for bolts. These are used when work is bored or turned true with a face which has been finished elsewhere. Crank boxes for engines are bored last of all. The strap is bolted to the face-plate on parallel strips.

VIII. The milling machine is provided with chuck and center to hold work much the same as in a lathe. A mandrel is provided for the spindle with bushings and a square thread nut to use in holding

gears. A vise is used on small work and keyseating shafts.

All work done by the milling machine must be so designed that a revolving cutter of set pattern can be used, which must not be damaged in any way. Hard cast iron or tool steel should be machined elsewhere. The tool-room tender has the care of this tool and should be consulted often.

IX. The tools of the planer or shaper are operated much the same as lathe tools, but the same diamond-point will not do for both, owing to the great slant of a lathe tool, which reduces the rake of the same tool in the shaper.

It is not best to always lift up the tool on the back stroke.

Some difficulty will be experienced in holding the work firmly and true in the chuck-vise of the shaper and planer. The jaws will spring when forced, and some personal instruction is needed. Parallel strips are often used to hold the work up.

In clamping work to the table of any machine, see that the work touches the table or a support directly under the clamp; otherwise it will spring, and when released it will not be true.

Planing requires judgment in the depth of the cut and style of finish. Some parts can be finished with a broad tool and quick feed, but bearing surfaces must be finished by a point.

X. In drilling, always clamp a surface of the

work, if possible, to the table or angle plate, which is at right angles to the table. Special instruction must be given in the use of boring bars and special drills. Always lay out the holes with dividers when possible, and drill every hole as true as you can. Drill holes for rough iron $\frac{1}{32}''$ large.

XI. True shafts can be made on the grinding machine, because both of the centers are dead centers. This is desirable for high-speed shafts, such as motors and emery grinder shafts.

All kinds of hardened work can be ground true; hardening causes the metal to swell in spots, which give the work a change in shape.

The work on the grinders is all close work and micrometer calipers are used. Many standard tools, reamers, plugs and gauges, are made here.

Many machines and tools are used which will not differ greatly from those mentioned.

APPENDIX.

To find the size of drill to use for a tap: Try the cutting end of the tap in the drill gauge and select a drill that will not cut quite a full thread.

To guide a tap straight into a hole that has just been drilled: Place the butt end of a small drill, which is pointed, in the press, and hold it firmly in the center of the tap while it is turned with a tap-wrench. Holes smaller than 3/8″ can be tapped with perfect safety in the lathe by allowing the drill chuck to turn in the tail-spindle as a guide and hold or turn the chuck and tap by hand.

To forge a square hole in the end of a bar of steel: Drill a hole the circumference of which equals the perimeter of the square desired; heat and pound the square bar round.

In shops where small center drills can not be used, use a slender, flat-ended punch to punch the hole.

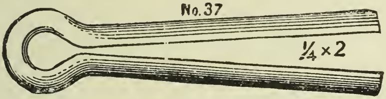
Square-pointed centers (pyramids) are often used in place of half-centers, and are used to cut the center true when the work is forced into its proper place by a tool-rest while revolving.

The cylindrical surface of work in the lathe can be divided into even sections by using a tool to mark the divisions and the teeth in the main gear as a dividing head.

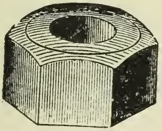
The Taylor-White steel is a steel lately invented that will permit the cutting speed of 150 feet per minute with water. It is not yet on the market. It will be used in shape similar to our self-hardening steel.

The self-hardening steel which is used in tool-holders on the lathe and planer can be heated by grinding, but should not be put in the water while hot.

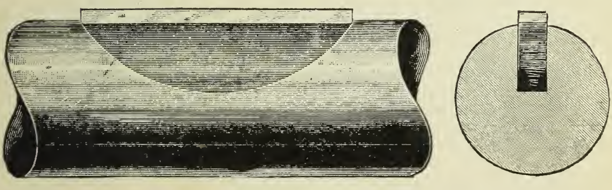
The following cuts serve to illustrate and show the names of the articles.



SPRING COTTER.



Nut



THE WOODRUFF PATENT SYSTEM OF KEYING.

The Sizing of Spur Gears.

The term "diametral pitch" is used to denote the relative number of teeth in connection with the diameter of a wheel at the pitch circle. A wheel 3″ in diameter at the pitch circle and containing 30 teeth is 10 pitch.

The pitch diameter is two parts of the pitch less than the whole diameter.

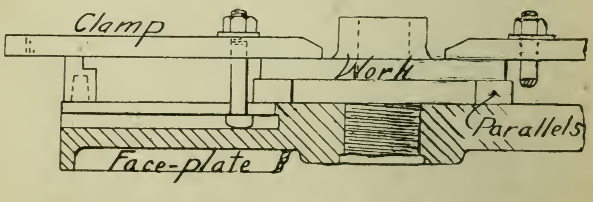
A wheel containing 30 teeth and of 10 pitch will be $\left(\frac{30}{10} + \frac{2}{P}\right) = \frac{30+2}{10} = 3.2''$ in diameter on the outside of the blank.

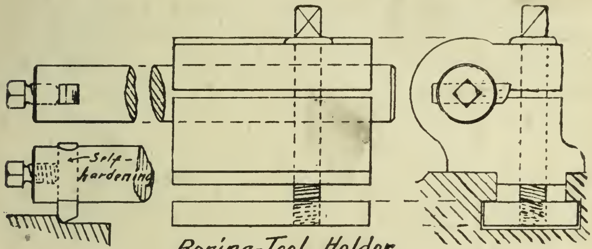
Let N = Number of teeth.
P = Pitch.
D = Diameter of blank.

FORMULA:
$$D = \frac{N+2}{P}$$

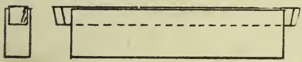
TABLE OF DEPTH OF SPACE OF SPUR WHEELS.

Pitch	20	18	16	14	12	10	8	6	5	4
Depth in Inches..	.108	.120	.135	.154	.180	.260	.270	359	.431	.539

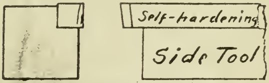




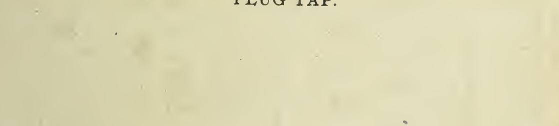
Boring-Tool Holder



Lathe-Tool Hoolder



Planer-Tool Holder



PLUG TAP.

Decimals of an Inch for Each 1-64th.

$\frac{1}{32}$ds	$\frac{1}{64}$ths	Decimal	Fraction	$\frac{1}{32}$ds	$\frac{1}{64}$ths	Decimal	Fraction
	1	.015625			33	.515625	
1	2	.03125		17	34	.53125	
	3	.046875			35	.546875	
2	4	.0625	$\frac{1}{16}$	18	36	.5625	$\frac{9}{16}$
	5	.078125			37	.578125	
3	6	.09375		19	38	.59375	
	7	.109375			39	.609375	
4	8	.125	$\frac{1}{8}$	20	40	.625	$\frac{5}{8}$
	9	.140625			41	.640625	
5	10	.15625		21	42	.65625	
	11	.171875			43	.671875	
6	12	.1875	$\frac{3}{16}$	22	44	.6875	$\frac{11}{16}$
	13	.203125			45	.703125	
7	14	.21875		23	46	.71875	
	15	.234375			47	.734375	
8	16	.25	$\frac{1}{4}$	24	48	.75	$\frac{3}{4}$
	17	.265625			49	.765625	
9	18	.28125		25	50	.78125	
	19	.296875			51	.796875	
10	20	.3125	$\frac{5}{16}$	26	52	.8125	$\frac{13}{16}$
	21	.328125			53	.828125	
11	22	.34375		27	54	.84375	
	23	.359375			55	.859375	
12	24	.375	$\frac{3}{8}$	28	56	.875	$\frac{7}{8}$
	25	.390625			57	.890625	
13	26	.40625		29	58	.90625	
	27	.421875			59	.921875	
14	28	.4375	$\frac{7}{16}$	30	60	.9375	$\frac{15}{16}$
	29	.453125			61	.953125	
15	30	.46875		31	62	.96875	
	31	.484375			63	.984375	
16	32	.5	$\frac{1}{2}$	32	64	1	1

Weights of Square and Round Bars of Wrought Iron in Pounds per Lineal Foot.—*Kent.*

Iron weighing 480 lbs. per cubic foot. For Steel add 2 per cent.

Thickness or Diameter in Inches.	Weight of Square Bar One Foot Long.	Weight of Round Bar One Foot Long.	Thickness or Diameter in Inches.	Weight of Square Bar One Foot Long.	Weight of Round Bar One Foot Long.
0			1 3-4	10.21	8.018
1-16	.013	.010	13-16	10.95	8.601
1-8	.052	.041	7-8	11.72	9.204
3-16	.117	.092	15-16	12.51	9 828
1-4	.208	.164	2	13.33	10.47
5-16	.326	.256	1-16	14.18	11.14
3-8	.469	.368	1-8	15.05	11.82
7-16	.638	501	3-16	15.95	12.53
1-2	.833	.654	1-4	16.88	13.25
9-16	1.055	.828	5-16	17.83	14.00
5-8	1.302	1.023	3-8	18.80	14.77
11-16	1 576	1 237	7-16	19.80	15.55
3-4	1.875	1.473	1-2	20.83	16 36
13 16	2.201	1.728	9-16	21.89	17.19
7-8	2.552	2.004	5-8	22.97	18.04
15-16	2.930	2.301	11-16	24.08	18.91
1	3.333	2.618	3-4	25.21	19.80
1-16	3.763	2 955	13-16	26.37	20.71
1-8	4.219	3.313	7-8	27.55	21.64
3 16	4.701	3.692	15-16	28.76	22.59
1-4	5.208	4.091	3	30.00	23.56
5-16	5.742	4.510	1-16	31.26	24.55
3-8	6.302	4 950	1-8	32 55	25 57
7-16	6.888	5.410	3-16	33.87	26.60
1-2	7.500	5.890	1-4	35.21	27.65
9-16	8.138	6.392	5-16	36.58	28.73
5-8	8.802	6.913	3-8	37.97	29.82
11-16	9.492	7.455	7-16	39 39	30.94

AREAS AND CIRCUMFERENCES OF CIRCLES.

Diam.	Area.	Circum.	Diam.	Area.	Circum.
$\frac{1}{64}$	.000192	.04909	$\frac{1}{2}$	15.9043	14.1372
$\frac{1}{32}$	.000767	.09818	$\frac{3}{4}$	17.7206	14.9226
$\frac{1}{16}$	.003068	.19635	5	19.635	15.708
$\frac{1}{8}$	.012272	.3927	$\frac{1}{4}$	21.6476	16.4934
$\frac{3}{16}$	.027612	.589	$\frac{1}{2}$	23.7583	17.2788
$\frac{1}{4}$	.049087	.7854	$\frac{3}{4}$	25 9673	18.0642
$\frac{5}{16}$	.076699	.98175	6	28.2744	18.8496
$\frac{3}{8}$	.110447	1.1781	$\frac{1}{4}$	30.6797	19.635
$\frac{7}{16}$	.15033	1.37445	$\frac{1}{2}$	33.1831	20 4204
$\frac{1}{2}$	.19635	1.5708	$\frac{3}{4}$	35.7848	21.2058
$\frac{9}{16}$	.248505	1.76715	7	38.4846	21.9912
$\frac{5}{8}$	.306796	1.9635	$\frac{1}{4}$	41.2826	22 7766
$\frac{11}{16}$	371224	2.15985	$\frac{1}{2}$	44.1787	23.562
$\frac{3}{4}$	.441787	2.3562	$\frac{3}{4}$	47 1731	24.3474
$\frac{13}{16}$	518487	2.55255	8	50.2656	25.1328
$\frac{7}{8}$	.601322	2.7489	$\frac{1}{4}$	53.4563	25.9182
$\frac{15}{16}$	.690292	2 94525	$\frac{1}{2}$	56.7451	26 7036
1	.7854	3.1416	$\frac{3}{4}$	60.1322	27 489
$\frac{1}{4}$	1.2272	3 927	9	63.6174	28.2744
$\frac{1}{2}$	1.7671	4.7124	$\frac{1}{4}$	67.2008	29 0598
$\frac{3}{4}$	2.4053	5 4978	$\frac{1}{2}$	70.8823	29 8452
2	3.1416	6.2832	$\frac{3}{4}$	74.6621	30.6306
$\frac{1}{4}$	3.9761	7 0686	10	78 54	31 416
$\frac{1}{2}$	4.9087	7.854	$\frac{1}{4}$	82 5161	32.2014
$\frac{3}{4}$	5.9396	8 6384	$\frac{1}{2}$	86.5903	32.9868
3	7.0686	9.4248	$\frac{3}{4}$	90.7628	33.7722
$\frac{1}{4}$	8.2958	10 2102	11	95.0334	34.5576
$\frac{1}{2}$	9.6211	10.9956	$\frac{1}{4}$	99.4022	35.343
$\frac{3}{4}$	11.0447	11 781	$\frac{1}{2}$	103 8691	36.1284
4	12 5664	12 5664	$\frac{3}{4}$	108 4343	36.9138
$\frac{1}{4}$	14 1863	13.3518	12	113 098	37 6992